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Heselhaus

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(54) **FILM-COOLED TURBINE BLADE FOR A TURBOMACHINE**

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F01D 5/18 (2006.01)

(52) **U.S. Cl.**
CPC ***F01D 5/186*** (2013.01); *F05D 2260/209* (2013.01); *F05D 2260/2212* (2013.01)

(58) **Field of Classification Search**
CPC B22C 7/02; B22C 7/06; B22C 9/04; B22C 9/10; F01D 5/186; F01D 5/187; F01D 5/14; F01D 5/147; F05D 2230/21
See application file for complete search history.

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Primary Examiner — Christopher Verdier

(57) **ABSTRACT**

A turbine blade for a turbomachine has an outer wall which delimits an inner cavity. Cooling fluid flows in the inner cavity. A through duct is arranged in the outer wall through which the cooling fluid flows from the inner cavity to an outside of the turbine blade. The through duct is inclined with respect to a trailing edge of the turbine blade, wherein a marginal portion of an entrance of the through duct is designed on an upstream side to be sharp-edged in relation to other marginal portions of the entrance such that a separation zone of a cooling fluid flow is formed in the through duct. A pair of swirls builds up in the through duct, wherein velocity vectors of the cooling fluid flow between the swirl centers point toward a downstream side of the through duct.

4 Claims, 3 Drawing Sheets

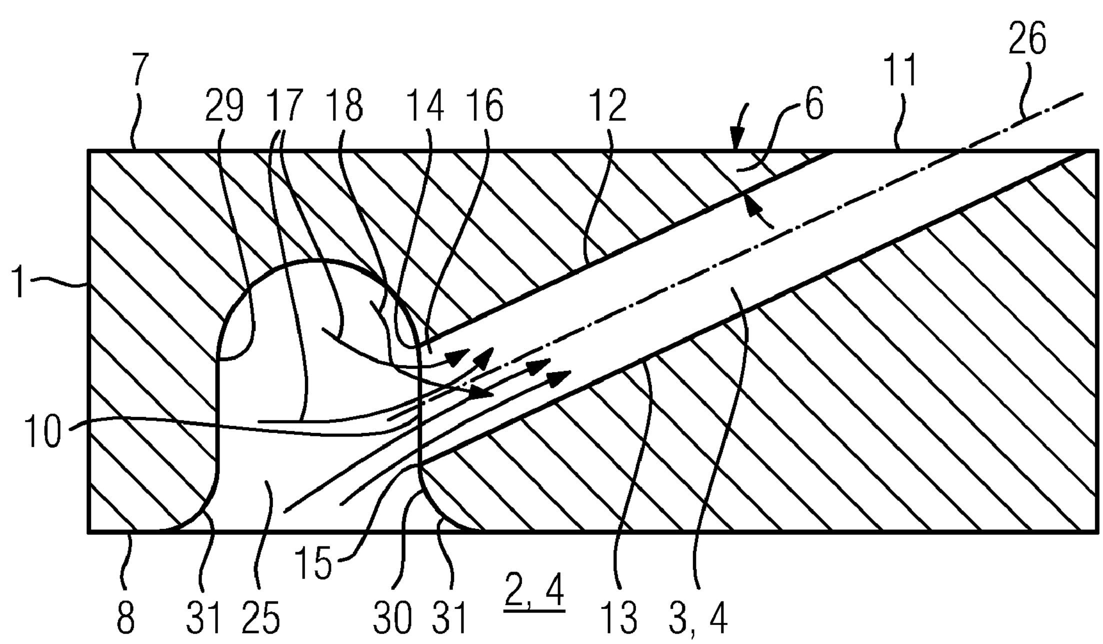

FIG 1

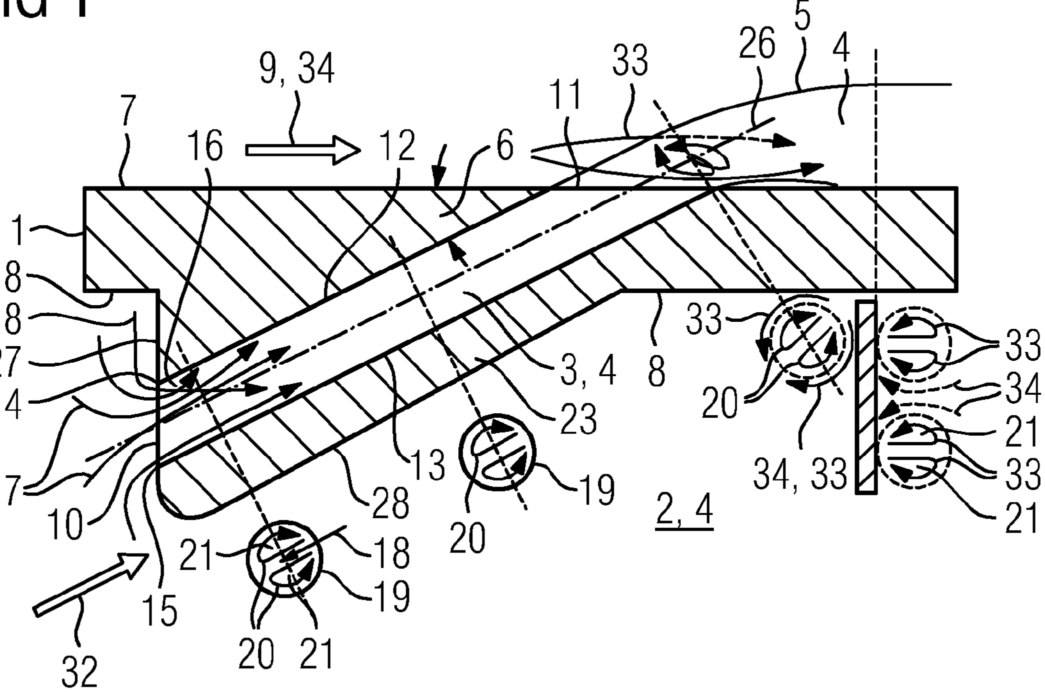
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FIG 2

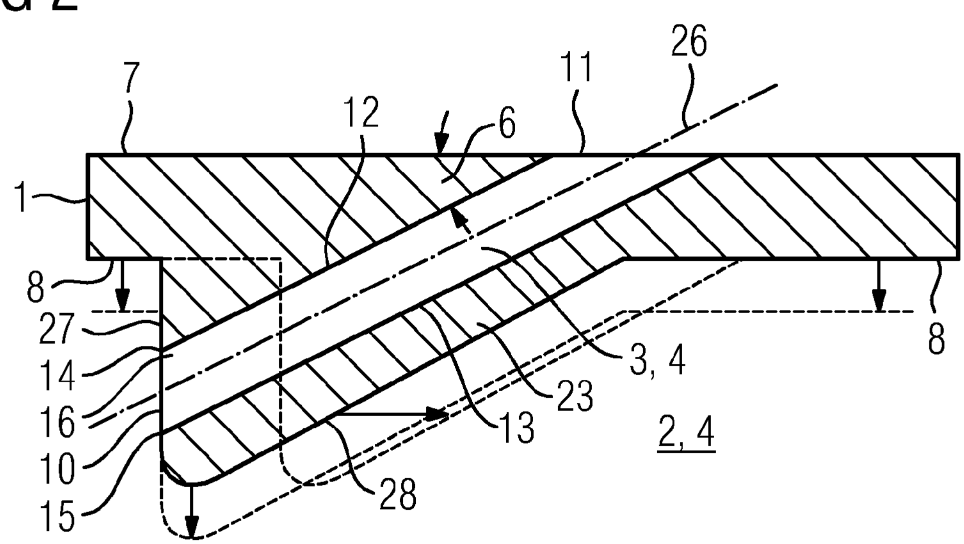
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FIG 3

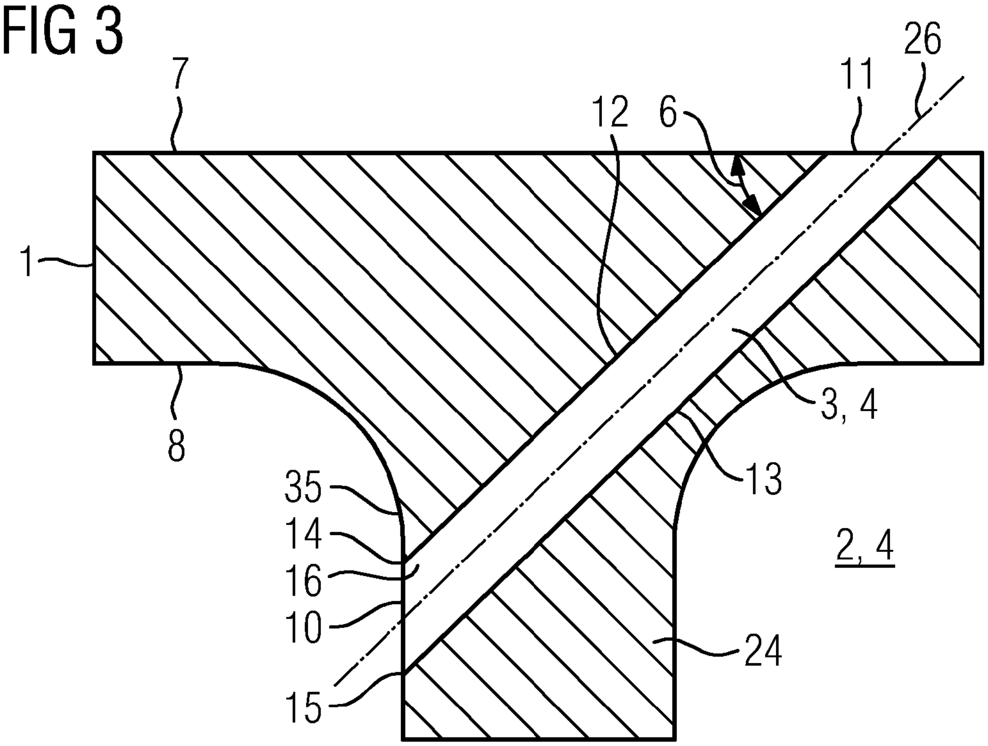
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FIG 4

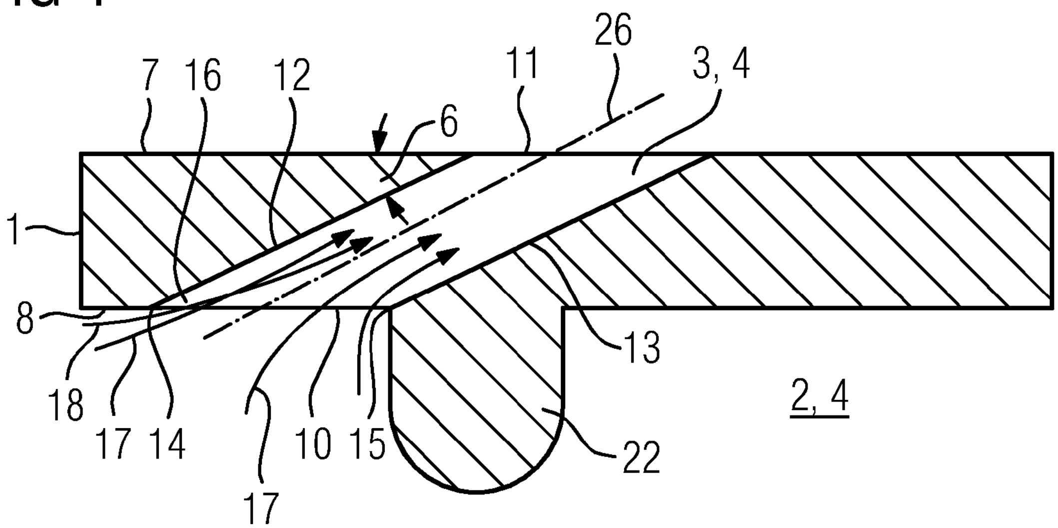
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FIG 5

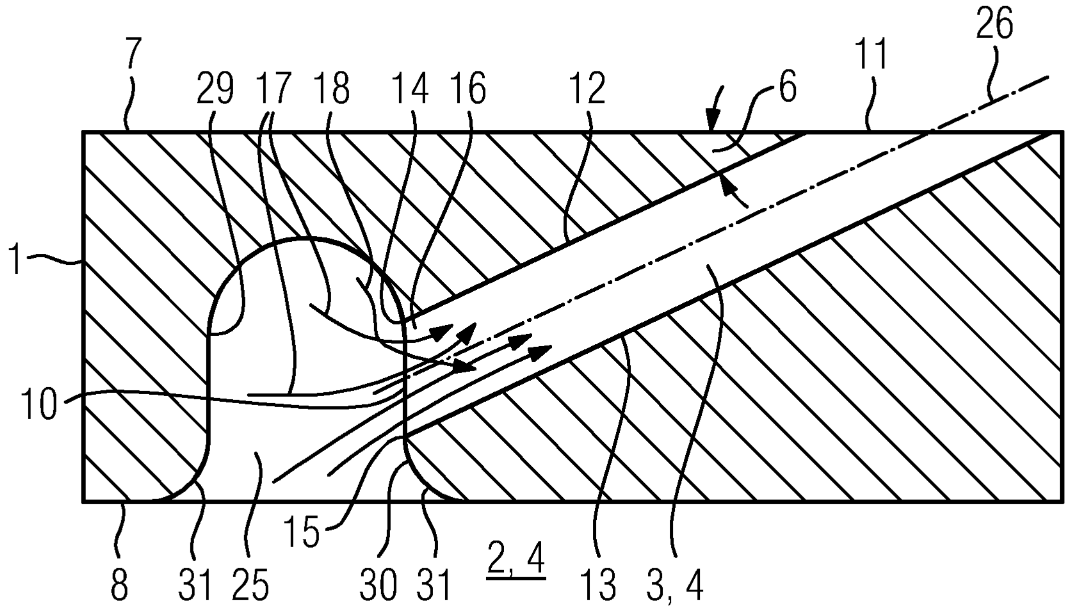
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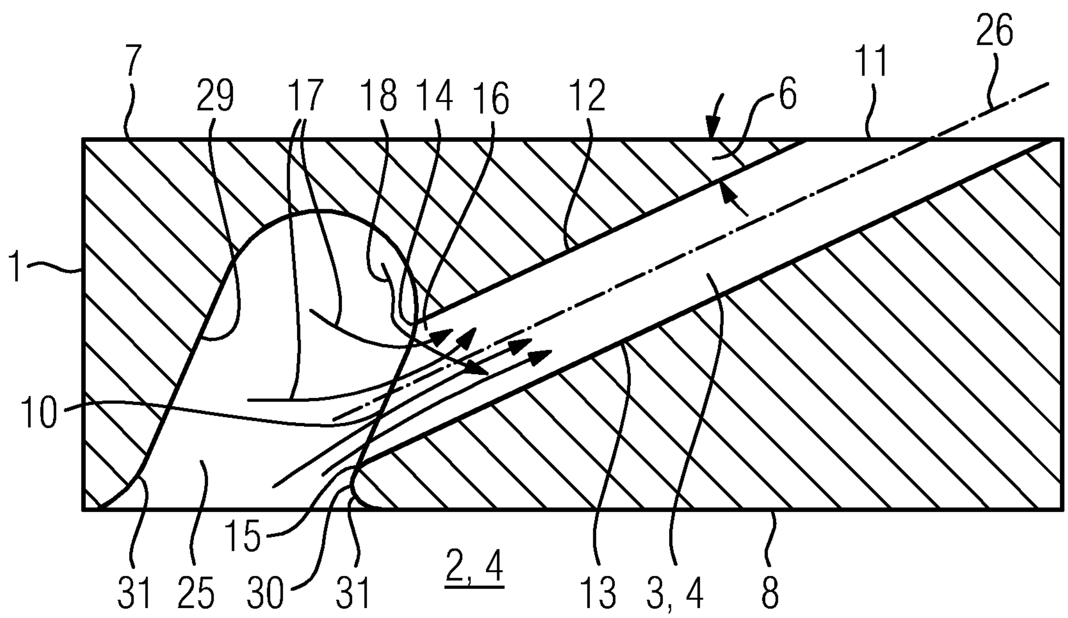
FIG 6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FILM-COOLED TURBINE BLADE FOR A TURBOMACHINE

FIELD OF INVENTION

A turbine blade for a turbomachine, the turbine blade being film-cooled, is provided.

BACKGROUND OF INVENTION

A turbomachine, in particular a gas turbine, has a turbine in which hot gas, which has previously been compressed in a compressor and heated in a combustion chamber, is expanded in order to perform work. For high mass flows of the hot gas and therefore for high power output ranges of the gas turbine, the turbine is designed in an axial type of construction, the turbine being formed by a plurality of blade rings lying one behind the other in the through-flow direction. The blade rings have moving blades and guide vanes arranged over the circumference, the moving blades being fastened to a rotor of the gas turbine and the guide vanes being fastened to the casing of the gas turbine.

The thermodynamic efficiency of the gas turbine is the higher, the higher the inlet temperature of the hot gas into the turbine is. By contrast, limits are placed upon the thermal load-bearing capacity of the turbine blades. It is therefore desirable to provide turbine blades which, despite as high a thermal load as possible, have mechanical strength sufficient for the operation of the gas turbine. For this purpose, appropriate materials and material combinations are available for the turbine blades, but, according to the current state of the art, allow only inadequate exploitation of the potential for increasing the thermal efficiency of the gas turbine. For a further increase in the permissible turbine inlet temperature, it is known to cool the turbine blades during the operation of the gas turbine, with the result that the turbine blade itself is exposed to lower thermal load than would be the case without cooling because of the thermal load caused by the hot gas.

In order to keep the temperature of the turbine blades low, the blades are cooled, for example, by means of film cooling. For this purpose, the blades are provided on their surface with a plurality of cooling air holes, via which cooling air is transported from the blade interior to the surface of the turbine blades. After the cooling air has left the cooling air holes, it flows in the form of a film along the surface of the turbine blade and thus insulates the surface of the turbine blade from the hot gas. Furthermore, the film acts as a barrier, so that transport of the hot gas to the surface of the turbine blade is suppressed.

SUMMARY OF INVENTION

An object is to provide a turbine blade for a turbomachine which is cooled effectively by film cooling.

The turbine blade for a turbomachine has an outer wall which delimits an inner cavity of the turbine blade. In the inner cavity cooling fluid is provided for film cooling of the turbine blade. At least one through duct is located in the outer wall through which the cooling fluid flows from the inner cavity to an outside the turbine blade so as to form a cooling film on an outer face of the outer wall. The at least one through duct is inclined with respect to a trailing edge of the turbine blade. A marginal portion of the entrance of the through duct is designed on an upstream side to be sharp-edged in relation to other marginal portions of the entrance such that a separation zone of the cooling fluid flow is formed in the at least one through duct. The separation zone induces a centric trans-

verse flow of the cooling fluid which is directed toward a side of the at least one through duct which lies opposite the separation zone. A pair of contra-directional vortices (swirls) develops in the at least one through duct, wherein velocity vectors of the cooling fluid flow between vortex centers point toward a downstream side of the at least one through duct.

When a hot gas from a combustion chamber of the turbomachine impinges on the outside of the turbine blade onto a jet of the cooling fluid which has emerged from the through duct, the flow of hot gas is divided around the jet, and a chimney vortex with two vortex arms is formed as a result of the drag effect of the hot gas at the jet margin. Each of the two vortex arms is formed by a vortex, the velocity vectors of the hot gas on the two inner faces of the vortex arms pointing away from the outer wall. The hot gas is thereby transported in the direction of the outside of the turbine blade. The two vortex arms of the chimney vortex have oppositely directed directions of rotation to the vortices, in each case overlaid with them, of the pair of contra-directional vortices of the cooling fluid. The chimney vortex is thus weakened and the transport of the hot gas to the outside of the turbine blade is reduced, with the result that the film cooling becomes more effective. As a result, the cooling fluid quantity necessary for cooling the turbine blade is lower than a cooling fluid quantity which would be necessary to cool a conventional turbine blade, this being accompanied by higher efficiency of the turbomachine. Furthermore, the selected density of arrangement of the through ducts in the turbine blade can be comparatively low, as result of which, overall, fewer through ducts are required for the turbine blade and structural weakening of the turbine blade is lower.

It is preferable that, on the inner face of that region of the outer wall in which the through duct is arranged, a thickening is provided, having an upstream front side in which the entrance is formed and which is inclined with respect to the axis of the through duct in such a way that the marginal portion of the entrance of the through duct is designed on its upstream side to be more sharp-edged than the opposite marginal portion of the entrance. The front side of the thickening is preferably arranged essentially perpendicularly to the inner face of the outer wall or at an inclination with respect to the trailing edge of the turbine blade. At the inclined front side of the thickening, an especially sharp-edged marginal portion is obtained on the upstream side of the through duct, with the result that the pair of contra-directional vortices is advantageously formed to an especially pronounced extent.

The thickening preferably has in its extent of thickness such large dimensioning that, in the case of the manufacturing inaccuracies which always occur during casting, the through duct is still arranged within the thickening and the entrance is formed by the front side of the thickening. The rear side of the thickening facing away from the front side of the thickening is preferably essentially parallel to the through duct. The thickening is preferably a cooling rib of the turbine blade. By the cooling rib being provided, the surface of the inside of the turbine blade is enlarged, with the result that the turbine blade can advantageously be cooled effectively from inside by the cooling fluid by convection. Alternatively, the thickening is preferably a supporting web running from the pressure side of the turbine blade to its suction side. The strength of the turbine blade is advantageously increased by the supporting web. Individual cooling ducts of the blade are formed in the blade interior by the supporting webs.

It is preferable that the thickening is a displacement body in the inner cavity of the turbine blade, by means of which displacement body the flow velocity of the cooling fluid in the inner cavity can be increased for the purpose of cooling the turbine blade, with the result that convection by the cooling fluid in the inner cavity is increased. The turbine blade can thereby likewise advantageously be cooled effectively from inside.

Alternatively, it is preferable that the inner face of that region of the outer wall in which the through duct is arranged is arranged essentially parallel to the outer face, and a bead is integrally formed on the marginal portion of the entrance of the through duct on its downstream side in such a way that this marginal portion is designed to be blunt in relation to the opposite marginal portion of the entrance. This shape for the turbine blade is simple to cast. In the event of manufacturing inaccuracies possibly occurring during the casting of the turbine blade, the ultimate position of the bead cannot be predicted exactly from the outset. In this case, the position of the bead can be determined subsequently with the aid of an X-ray method. On the basis of this determined position, the through duct can be produced in the correct position in relation to the bead from outside the turbine blade, for example by drilling.

On the inner face of that region of the outer wall in which the through duct is arranged, a clearance is preferably provided, having a downstream rear side in which the entrance is formed and which is inclined with respect to the axis of the through duct in such a way that the marginal portion of the entrance of the through duct is designed on its upstream side to be more sharp-edged than the opposite marginal portion of the entrance. By the clearance being provided, the demand for material for producing the turbine blade is low. Preferably, the rear side of the clearance is arranged essentially perpendicularly to the inner face of the outer wall or at an inclination with respect to the trailing edge of the turbine blade. The inclined rear side advantageously gives rise to an especially sharp-edged marginal portion on the upstream side of the through duct. The clearance preferably is of round shape at its inlet margin in such a way that the cooling fluid can flow, free of separation, into the clearance.

The shape of the turbine blade is appropriate for casting purposes, with the result that it becomes possible that the turbine blade can be produced by casting without any further adaptations. The through ducts are preferably to be produced by drilling, in particular laser drilling, or erosion. Drilling is usually carried out from outside the turbine blade.

The clearance is preferably a groove into which a plurality of through ducts issue. In this case, it is advantageously simpler, during drilling, to find the groove and at the same time form the marginal portions.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1** and **2** show a longitudinal detail of an outer wall of the turbine blade with a through duct and with a thickening.

FIG. **3** shows a longitudinal detail of an outer wall of the turbine blade with a through duct and with a supporting web.

FIG. **4** shows a longitudinal detail of an outer wall of the turbine blade with a through duct and with a bead.

FIGS. **5** and **6** show a longitudinal detail of an outer wall of the turbine blade with a through duct and with a clearance.

DETAILED DESCRIPTION OF INVENTION

FIGS. **1** to **6** show a portion of an outer wall **1** of a turbine blade of a turbomachine. The outer wall **1** delimits an inner cavity **2** and has an outer face **7** and an inner face **8**. When the turbomachine is in operation, a hot gas flow **34** occurs on the outer face **7**, with a hot gas main flow direction **9** which is parallel to the outer face **7** and which is directed toward the trailing edge of the turbine blade (not shown in the figures). A through duct **3** of circular cross section **19** is introduced into the outer wall **1** and is inclined with respect to the trailing edge of the turbine blade in the through-flow direction directed from the inside outward and forms an acute inclination angle **6** with the outer face **7**.

The through duct **3** in FIGS. **1** to **6** has an entrance **10** on the inside and an exit **11** on the outside. Furthermore, the through duct **3** has an axis **26**, an upstream side **12** and a downstream side **13**. The entrance **10** of the through duct **3** has an upstream marginal portion **14** on the upstream side **12** and a downstream marginal portion **15** on the downstream side **13**. When the turbomachine is in operation, the inner cavity **2** contains a cooling fluid **4** which penetrates via the entrance **10** into the through duct **3** and leaves the through duct **3** again via the exit **11**. The inclination angle **6** selected is acute, in such a way that the cooling fluid **4**, after leaving the through duct **3**, forms a cooling film **5** on the outer face **7**.

FIG. **1** shows an embodiment of the turbine blade with a thickening **23**. The thickening **23** is arranged on the inside on that region of the outer wall **1** in which the through duct **3** is arranged. The thickening **23** has a downstream thickening rear side **28**, which runs parallel to the through duct **3**, and an upstream thickening front side **27**, in which the entrance **10** is arranged. The thickening front side **27** is arranged essentially perpendicularly to the inner face **8** of the outer wall **1**, the upstream marginal portion **14** being designed to be more sharp-edged than the downstream marginal portion **15**.

The flow conditions at the turbine blade are described below with reference to FIG. **1**. The downstream marginal portion **15** is blunt, in such a way that the cooling fluid flow **17** can follow this marginal portion **15** so as to be separation-free. The upstream marginal portion **14** is sharp-edged, in such a way that the cooling fluid flow **17** cannot follow this marginal portion **14**, so that a separation zone **16** of the cooling fluid flow **17** is formed in the through flow duct **3** on the upstream side **12**. The separation zone **16** induces in the through duct **3** a centric transverse flow **18** which is directed from the upstream side **12** to the downstream side **13**. On account of the centric transverse flow **18**, a contra-directional pair of vortices **20** with two vortex centers **21** is generated in the through duct **3**, the velocity vectors between the two vortex centers **21** pointing toward the downstream side **13** of the through duct **3**.

As is clear from FIG. **1**, the velocity vectors of the cooling fluid flow **17** between the vortex centers **21**, immediately after leaving the through duct **3**, are directed toward the outer wall **1**. The hot gas flow **34** flows around the emerging cooling air jet having the contra-directional pair of vortices **20**, with the result that a chimney vortex **33** is formed from a hot gas. The chimney vortex **33** has two vortex arms which are arranged on opposite sides of the contra-directional pair of vortices **20**. Each of the vortex arms is formed by a vortex, the velocity vectors of the hot gas flow **34** between the vortex centers **21** of the vortex arms being directed toward the outer wall **1**. The hot gas is thereby transported onto the outer face **7** of the outer wall **1**. The vortex arms have oppositely directed directions of rotation to the vortices, in each case overlaid with them, of the pair of contra-directional vortices **20** immediately after leaving the through duct **3**, so that the chimney vortex **33** is weakened and the transport of the hot gas onto the outer face **7** of the outer wall **1** is reduced, with the result that the introduction of heat into the outer wall **1** of the turbine blade is diminished.

It is conceivable that the thickening front side **27** is inclined with respect to the trailing edge of the turbine blade, the upstream marginal portion **14** being designed to be even more sharp-edged than in FIG. **1**.

FIG. **2** illustrates the thickening **23** from FIG. **1**, with two extreme manufacturing inaccuracies, in each case indicated by a dashed line, in the case of the first manufacturing inaccuracy an offset of the thickening **23** parallel to the outer wall **1** occurring, and in the case of the second manufacturing inaccuracy an offset parallel to the thickening front side **27** occurring. In the case of both manufacturing inaccuracies, the through duct **3** is arranged within the thickening **23** and the entrance **10** is arranged in the thickening front side **27**.

The embodiment of the turbine blade from FIG. **3** has a supporting web **24** running from the pressure side of the turbine blade to its suction side. The through duct **3** runs partially in the supporting web **24** and the entrance **10** is arranged in the upstream supporting web front side **35**.

As is clear from FIG. **4**, a bead **22** is integrally formed on the inner face **8** of the outer wall **1** directly adjacently to the downstream marginal portion **15**, with the result that the downstream marginal portion **15** is of blunt form. The bead **22** has a convex region on its inwardly directed side. It is conceivable that the convex region extends as far as the downstream marginal portion **15** and/or into the through duct **3**. In this case, a separation zone could be avoided especially effectively on the downstream side **13** of the through duct **3**. It is conceivable that the bead **22** is designed with rectangular cross section. It is conceivable, furthermore, that the bead **22** is also designed as a cooling rib.

In the embodiments according to FIGS. **5** and **6**, a hat-shaped clearance **25** with an upstream clearance front side **29** and with a downstream clearance rear side **30** is arranged in the outer wall. The entrance **10** is arranged in the clearance rear side **30**. The clearance **25** has a clearance inlet margin **31** of round shape, in order to avoid a separation of the cooling fluid flow **17** when it enters the clearance **25**. In contrast to the embodiment from FIG. **5**, the clearance **25** of the embodiment from FIG. **6** is inclined with respect to the trailing edge of the turbine blade, the upstream marginal portion **14** being designed to be especially sharp-edged. It is conceivable, furthermore, that the clearance **25** is designed as a groove into which a plurality of through ducts **3** lead.

While specific embodiments have been described in detail, those with ordinary skill in the art will appreciate that various modifications and alternative to those details could be developed in light of the overall teachings of the disclosure. For example, elements described in association with different embodiments may be combined. Accordingly, the particular arrangements disclosed are meant to be illustrative only and should not be construed as limiting the scope of the claims or disclosure, which are to be given the full breadth of the appended claims, and any and all equivalents thereof. It should be noted that the term "comprising" does not exclude other elements or steps and the use of articles "a" or "an" does not exclude a plurality.

The invention claimed is:

1. A turbine blade for a turbomachine, comprising:

an outer wall which delimits an inner cavity of the turbine blade, wherein cooling fluid is provided in the inner cavity for film-cooling of the turbine blade,

at least one through duct arranged in the outer wall, wherein the cooling fluid flows through the at least one through duct from the inner cavity to an outside of the turbine blade so as to form a cooling film on an outer face of the outer wall,

wherein the at least one through duct is inclined with respect to a trailing edge of the turbine blade,

wherein a marginal portion of an entrance of the at least one through duct is designed to be sharp-edged on an upstream side in relation to other marginal portions of the entrance such that a separation zone of a cooling fluid flow is formed in the at least one through duct,

wherein the separation zone induces a centric transverse flow of the cooling fluid which is directed toward a side of the at least one through duct which lies opposite the separation zone,

wherein a pair of contra-directional vortices develops in the at least one through duct such that velocity vectors of the cooling fluid flow between vortex centers point toward a downstream side of the at least one through duct, and

a clearance provided on an inner face of the outer wall in which the at least one through duct is arranged,

wherein the clearance is hat-shaped such that the clearance includes a clearance inlet margin that is rounded,

wherein the clearance has a downstream rear side in which the entrance is formed and the entrance is inclined with respect to an axis of the at least one through duct such that the marginal portion of the entrance of the at least one through duct is designed on the upstream side to be more sharp-edged than an opposite marginal portion of the entrance.

2. The turbine blade as claimed in claim **1**, wherein the rear side of the clearance is arranged essentially perpendicularly to the inner face of the outer wall or at an inclination with respect to the trailing edge of the turbine blade.

3. The turbine blade as claimed in claim **1**, wherein the clearance is of round shape at an inlet margin such that the cooling fluid flows into the clearance free of separation.

4. The turbine blade as claimed in claim **1**, wherein the clearance is a groove, and wherein a plurality of through ducts leads into the groove.

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